Search for Faint Nearby Stars

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1. Introduction

Some of the most frequently discussed subjects in the astronomical literature during the last decades are related to the problem of the "missing mass" or dark matter in the Universe. The possibility that the "missing mass" in the solar neighbourhood might be accounted for by the existence, in sufficient numbers, of very low mass stars (brown dwarfs), and very old dead stars observed now as cold low luminosity degenerates is very attractive. See for example the works by D'Antona and Mazzitelli (1986) and Liebert, Dahn and Monet (1988). The solar neighbourhood is the only place where one might expect to find and study such low luminosity objects.

Luyten's LHS Catalogue (Luyten, 1979), containing stars with proper motions larger than 0.5 arcsec/year, is still the main source of nearby stars considered by different authors in their estimates of the contribution to the local dark matter due to brown dwarfs and cold degenerates. Unfortunately Luyten's LHS Catalogue, which is the source of many interesting results, is not adequate for the purpose of selecting a statistically significant sample of nearby faint stars because it is incomplete for m > 19 while the magnitudes of the relevant objects (brown dwarfs and cold degenerates) are M ≥ 16. Therefore, the volume for which the sample is complete is very small. The LHS Catalogue is also incomplete for proper motions smaller than about 0.7 arcsec/year, introducing a strong kinematical bias.

In 1986 we began a programme to search for and study faint nearby stars using glass copies of the ESO R Survey plates. The magnitude limit of these plates is about $m_R = 21$. We selected areas near 12 h and 0 h of right ascension, hoping to identify faint members of the Hyades and Sirius Superclusters (Eggen, 1984), which in these regions should have most of their space motions in the plane of the sky.

During the blinking process we found that for most stars, that is those with m > 13, displacements down to 0.7 arcseconds from one plate to the other could be detected. For instance, in area 439 we have a time base of 7 years and we found 160 stars with proper motions larger than 0.1 arcsec/year. In what follows we will describe the statistics of the proper motions in area 439 and the interesting potential of these studies in understanding the solar neighbourhood. We will also present some results of a spectroscopic follow-up for a selected group of proper motion stars found in area 439.

2. The Search

For this project we obtained glass copies of pairs of plates taken at La Silla for the ESO R Survey (IIIaF + RG 630) with time intervals from 3 to 7 years. They were searched using a Zeiss Jena stereocomparator (blink). Every single image was carefully checked for proper motion. It takes some 50 hours to scan a pair of plates.

Coordinates α, δ for each star were determined using the Perth 70 stars as reference. To measure proper motions we divided each plate into 9 zones 10 cm by 10 cm each. With an x-y measuring engine (Zeiss Jena) we measured the proper motion stars in each zone along with a group of 25 reference stars selected to be faint (about 18th magnitude) and evenly spaced in each zone.

A simple computer programme was developed to map one plate into the other through a linear transformation. This was done for each zone separately. The reference stars were used for this purpose. The rms errors achieved after discarding from 4 to 7 reference stars were always less than 2 μm, typically 1.6 μm. The x-y measuring engine has a precision of the order of 1.2 μm, therefore the rms errors achieved with our method are getting down to the measuring errors. When the final transformation equations were found the proper motion was computed for every programme star previously selected. Typically, for a 5-year time base, the formal error is about 0.02 arcsec/year.

3. ESO Area 439: Statistics of Proper Motions

For this area we have two plates taken 7 years apart. We have found 250 stars

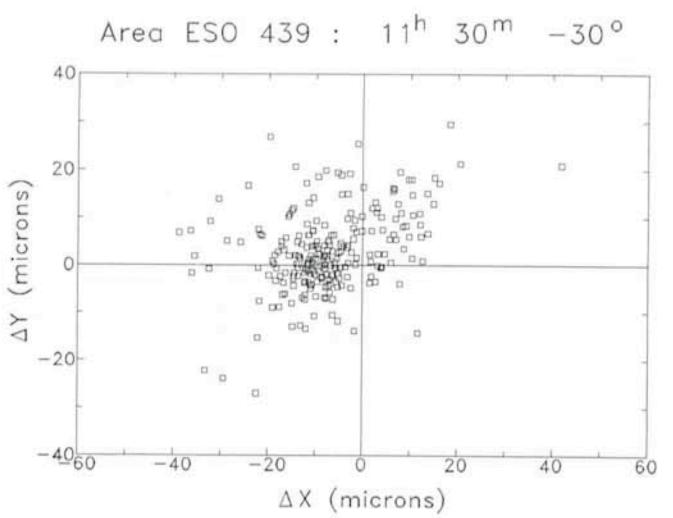


Figure 1a: *Δx versus Δy for 250 proper motion stars found in area ESO 439.*

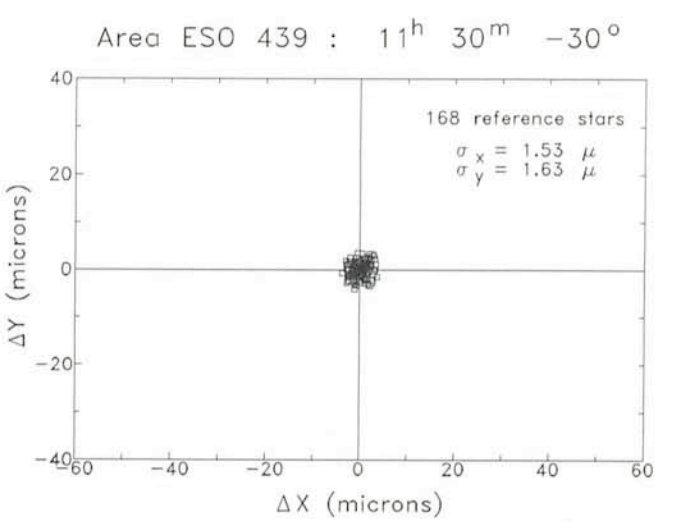


Figure 1b: *Δx versus Δy for 168 reference stars used to obtain the stellar motions. The average residuals for x and y are indicated.*

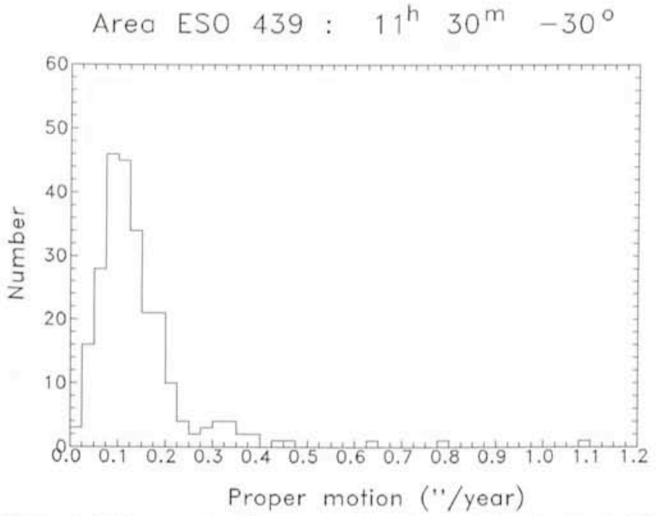


Figure 2: *Histogram showing proper motion stars binned every 0.025 arcsec/year. The apparent magnitudes of the sample are distributed as 21 % with $m_R \leq 15$; 54 % with $15 < m_R \leq 18$ and 25 % fainter than 18th magnitude.*

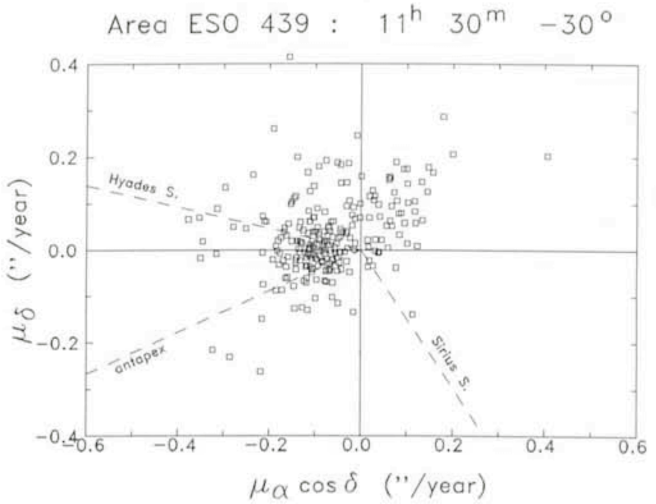


Figure 3: *Same as Figure 1a but showing the proper motions. Drifts' directions due to Hyades and Sirius superclusters and the general drift towards the antapex are indicated.*

with detectable proper motions, including 7 common proper motion pairs. Figure 1a shows the x and y displacements in microns for all the programme stars. Figure 1b shows the same for 168 reference stars used for the whole plate (an average of 18.7 stars per zone). Comparing Figure 1a and 1b, it is clear that this method of detecting and measuring proper motions works for stars with proper motions down to about 0.05 arcsec/year for a time base of 7 years. In Figure 2 we present a histogram of the proper motions in area 439.

Figure 3 shows $\mu_\alpha \cos_\delta$ vs. μ_δ for the proper motion stars in area ESO 439. The direction towards which stars should be drifting if they were members of the Hyades Supercluster, the Sirius Supercluster and the general drift towards the antapex are indicated. There seems to be a large proportion of stars with proper motions compatible with membership in the Hyades Supercluster or sharing the general drift towards the antapex. Only one star might belong to the Sirius Supercluster in area 439.

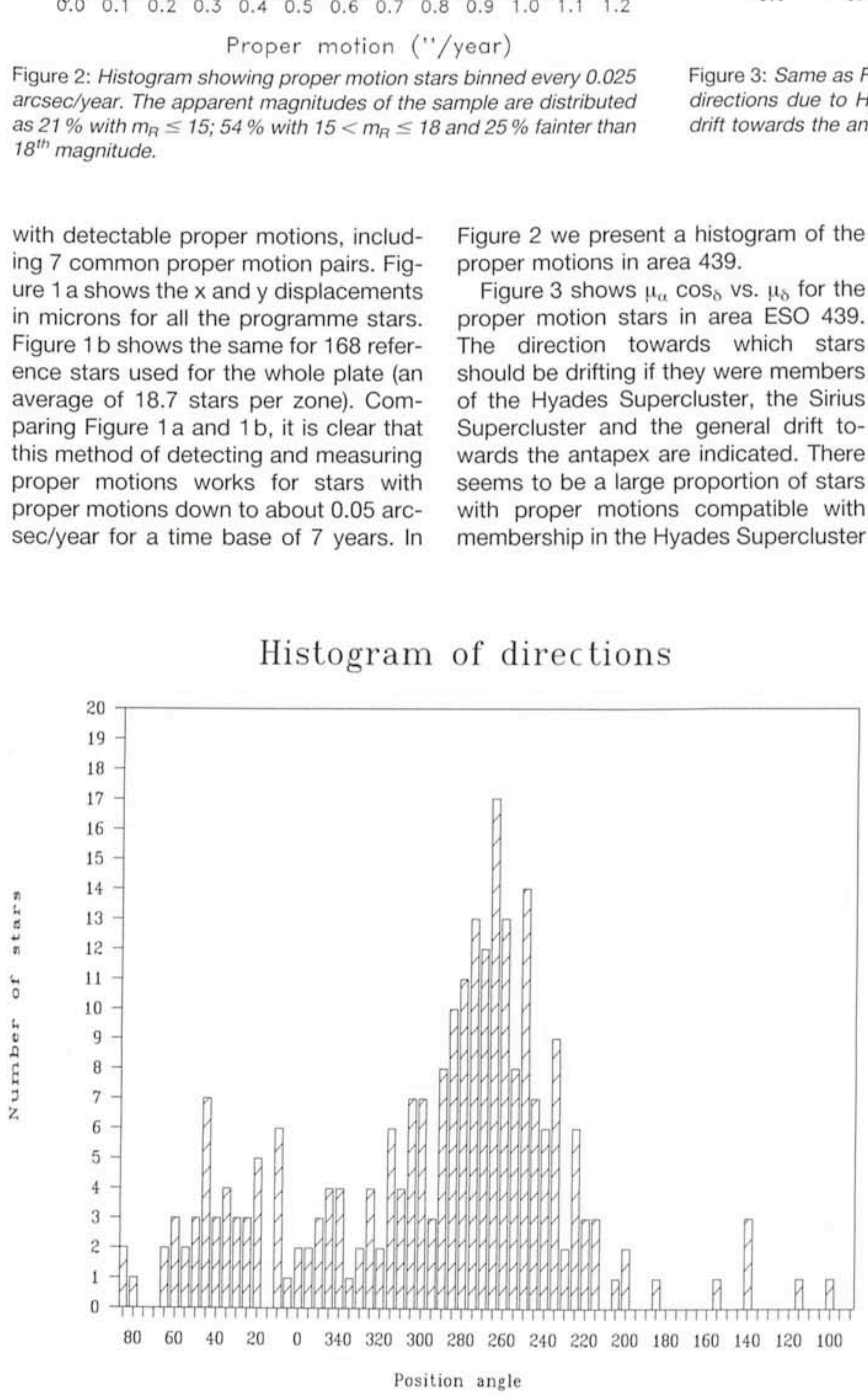
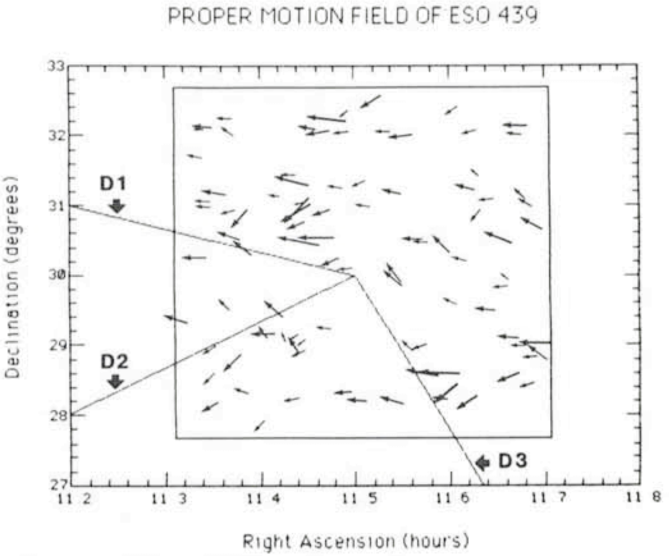


Figure 4: *Histogram showing proper motion's directions of the stars in area 439. Two maxima are evident centred at P.A. = 268° and P.A. = 38° (P.A. is measured from north through east).*

From Figure 3, it is clear that the stars in area 439 do not have random motions; instead, they seem to be oriented towards certain directions. This is even more evident from Figure 4, where the motion's directions (position angles) distribution is shown. The histogram has two peaks: the main one is centred at P.A. = 268°, and contains members of the Hyades Supercluster and stars reflecting the solar motion (drifting towards the antapex); in addition, a second maximum at P.A. = 38° is clearly evident. The lack of stars moving towards directions between 100° and 200° is striking. In Figures 5a and 5b the two main streams (at 268° and 38°) are graphically shown. The size of the arrows is approximately proportional to the proper motions.

It has been suggested (Elmegreen, 1983) that in the galactic plane molecular clouds with low mass cores could be the sites of a very efficient star forming process, giving birth preferentially to low mass stars which quietly evolve while remaining gravitationally bound as a group. This prediction has not been supported by observations. Very few groups of this kind have been found, partly due to the intrinsic faintness of low mass stars. This makes their observations difficult unless they are nearby, in which case any such group will extend over a large fraction of the sky and would not be easily identified as a star cluster.

The star stream at 38° found in area 439, might be one of these low mass stars aggregates. This idea is supported by the fact that stars belonging to this stream show a flatter μ distribution be-



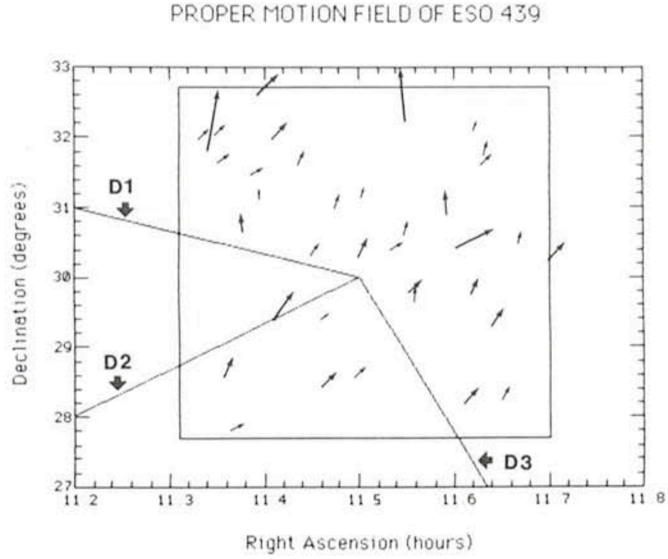


Figure 5a: *Proper motions of stars in area ESO 439 with directions centred around P.A. = 268°. D1, D2 and D3 correspond to the directions of the Hyades supercluster, antapex and Sirius supercluster drifts. It is clear that the stars shown are either members of the Hyades S. or are drifting towards the antapex. The size of the arrows is approximately proportional to the proper motions.*

Figure 5b: *Same as Figure 5a for stars in the 38° stream.*

tween 0.100 and 0.200 arcsec/year, with very few stars with μ between 0.085 and 0.100 arcsec/year where the maximum number of stars is found for the complete sample shown in Figure 2. This suggests that stars belonging to the 38° stream occupy a small volume in space with dimensions equal to about half the distance to the group. The typical magnitude of these stars is m(R) = 18.

4. ESO 439: The Spectrophotometric Follow-up

Low resolution spectra of the stars in area 439 with proper motions larger than 0.3 arcsec/year have been obtained at the CTIO 4-m telescope using a 2D Frutti detector and at the La Silla 3.6-m telescope with the EFOSC. As a result we found that from a total of 13 stars with $\mu > 0.3$ arcsec/year and $10 < m(R) < 21$ in area 439, eight are M dwarfs, one is a possible DA white dwarf and the other four stars are low luminosity degenerates with $M(V) > +15$.

As an example of the interesting objects found in this plate, we present in Figure 6 the spectra, obtained at La Silla in March 1988, using the 3.6-m telescope with EFOSC (B 300 grism and the RCA # 3 chip), of a faint common proper motion pair (with $\mu = 0.38$ arcsec/year formed by a cold degenerate (ESO 439-163) and a magnetic white dwarf (ESO 439-162) showing the Swan bands of C_2 broadened by a magnetic field of about 10^8 G. The spectrum of the cold degenerate ESO 439-26 is shown in Figure 7. Its trigonometric parallax, obtained by C. Anguita and M.T. Ruiz using a CCD at the CTIO 1.5-m telescope, is $\Pi = 0''.0240$ (with $\mu = 0.397$ arcsec/year), placing the star at a distance of 41.7 pc. Considering that the apparent visual magnitude of this star is ≈ 20, and that the bolometric correction for it should be B.C. ≤ 1, the luminosity of ESO 439-26 turns out to be $L \approx 3 \times 10^{-5} L_\odot$ (with $M_{bol} \approx 16$). Faint degenerates like ESO 439-26 have escaped detection in spectroscopic surveys of proper motion stars, and so far only a handful of them have been found. The importance of finding out the frequency of these objects in the solar neighbourhood is crucial when trying to account for the missing mass, given that they are massive objects, that is, they have masses of the order of 1 $M_\odot$, compared to less than 0.1 $M_\odot$ for M dwarfs and brown dwarfs of similar luminosities; relatively few cold degenerates are needed to acount for the missing mass in the solar neighbourhood.

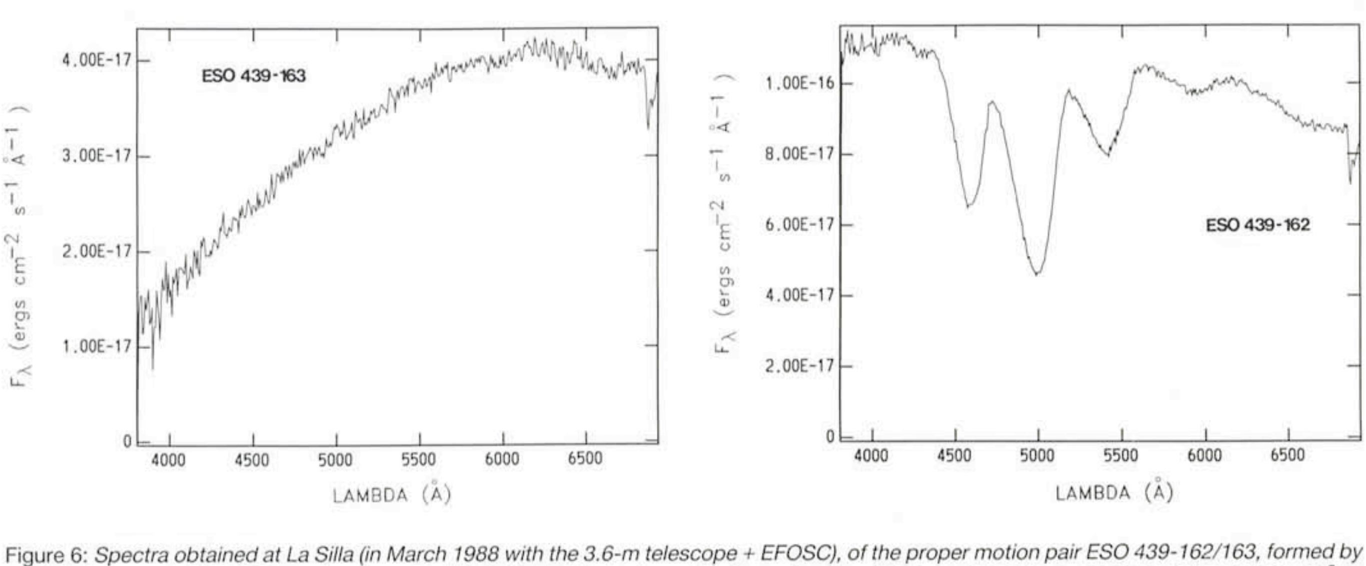


Figure 6: *Spectra obtained at La Silla (in March 1988 with the 3.6-m telescope + EFOSC), of the proper motion pair ESO 439-162/163, formed by a cold degenerate (439-163) and a magnetic WD (439-162) that shows the Swan bands of C_2 broadened by a magnetic field of about 10^8 G.*

In ESO area 439 we have found 4 low luminosity degenerates, that is 30% of the stars between $10 \leq m \leq 21$ and $\mu \geq 0.3$ arcsec/year) belong to this group. If this holds true for the whole sky, we then estimate that the missing mass might be accounted for by these faint objects.

Acknowledgements

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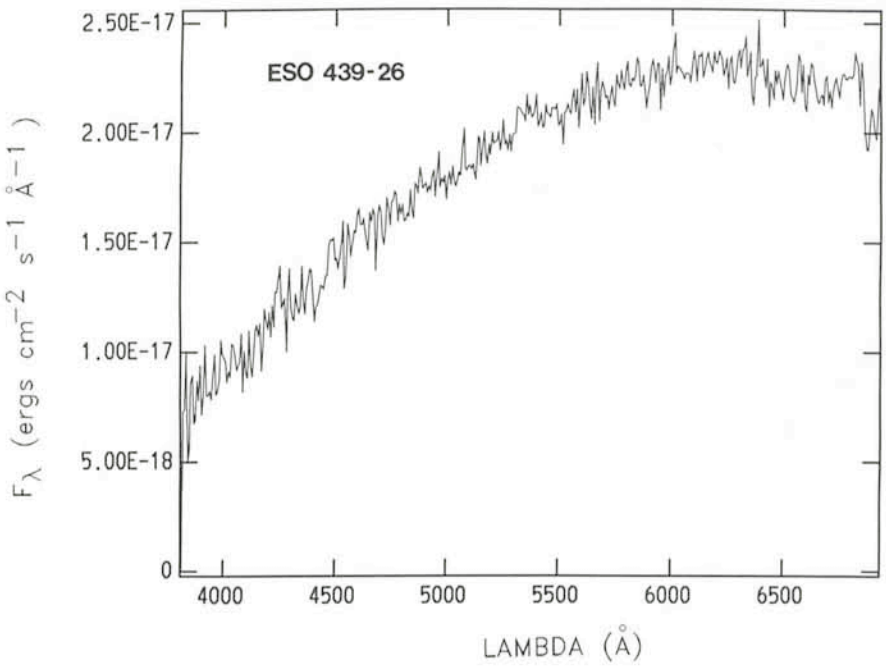

Figure 7: *Spectrum of the cold degenerate ESO 439-26. At a distance of 41.7 pc (measured by trigonometric parallax) its luminosity is $L \approx 3 \times 10^{-5} L_\odot$.*

A Search for Magnetic Fields in Blue Stragglers of M 67

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Introduction

Blue stragglers (hereafter BS) are members of star clusters whose location in the HR-diagram of the cluster is beyond the turnoff point, in the vicinity of the zero age main sequence (ZAMS). The existence of these stars appears to be in contradiction with the current views about the formation of star clusters and the stellar evolution. Namely, if all the stars belonging to a cluster have formed contemporaneously, standard evolution theory does not predict the presence of stars in the region of the HR-diagram where BS are found.

Various tentative explanations of the BS phenomenon have been put forward. The most popular ones are that BS:

(i) have formed later than the rest of the cluster,

(ii) result from mass exchange in close binaries, with the consequence that the former secondary component of the pair has moved up the main sequence,

(iii) are coalesced stars (an extreme case of mass transfer),

(iv) are stars undergoing quasi-homogeneous evolution.

The latter hypothesis can be intuitively understood as follows: if mixing takes place inside a star, part of the processed material in the core is moved up to outer layers and is replaced in the central stellar regions by unprocessed material, so that core hydrogen burning can last longer and main sequence lifetime is accordingly extended. Recent detailed modelling carried out by Maeder (1987) actually shows that, at least for massive stars, a star that undergoes internal mixing, rather than evolving along the standard redwards track in the HR-diagram, would as it ages raise bluewards near the ZAMS, and would thus be observed as a BS.

The main observable manifestation of quasi-homogeneous evolution, apart from the BS nature of the star, is expected to be the appearance of nuclear processed material from the core on the stellar surface. More precisely, the abundances of carbon and nitrogen determined from the analysis of the stellar spectrum should markedly differ from the standard main sequence abundances of these elements and be characteristic of the CN-equilibrium in the CNO cycle of hydrogen burning. On the other hand, the triggering agent responsible for the mixing of the stellar interior could possibly als reveal itself to observation. Internal mixing of a star could for instance be induced by turbulent diffusion resulting from rapid rotation or from tidal forces in binaries, or could be produced by magnetic buoyancy.

The BS of M 67

In order to get a new insight into the nature of BS, I initiated a programme of observations of the BS of M 67, with the aim of testing the hypothesis that they are quasi-homogeneously evolved stars.

M 67 (= NGC 2682) is one of the oldest galactic clusters known (with an age of 3.5 10^9 yr), and one of those having the richest BS populations. A colour-magnitude diagram of M 67 is shown in Figure 1, which was kindly provided by J.-C. Mermilliod. V is plotted against B-V for all the stars having a membership probability higher than 80% and $V < 16$ for which Mermilliod has been able to compute average photometric parameters from measurements found in the literature. The BS, represented by filled squares, are easily distinguished. Their spectral types range from late B to early F; most of them are thus A-type stars.

The main goal of the observing programme is to determine the abundances of C, N and O in the BS of M 67 in order to see whether they have standard main